



Beam-Induced HEDS

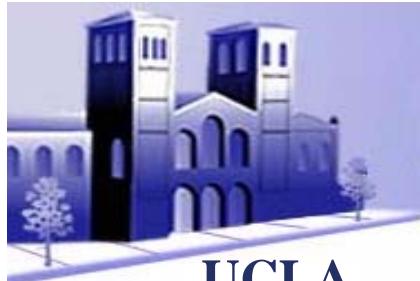
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UCLA

HEDS Workshop
May 24-27 2004



High Energy Density Plasma Science: Driver Comparison

	1 PW	50 GeV Electron Beam
Energy per particle (ev)	1.5	5×10^9
Pulse Length (FWHM) (fs)	30	50
Spot Size (μm)	1	1
Energy/pulse (J)	30	300
Rep Rate (Hz)	10	100
Peak Intensity (W/cm^2)	$>10^{22}$	10^{23}



UCLA

HEDS with ULTRA- RELATIVISTIC ELECTRON BEAMS

$$\gamma = (1 - \beta^2)^{-1/2} \gg 1$$

$$\beta = v/c$$

STIFF BEAM

LONGITUDINAL MOTION NOT IMPORTANT

FOUR REGIMES OF INTERACTION

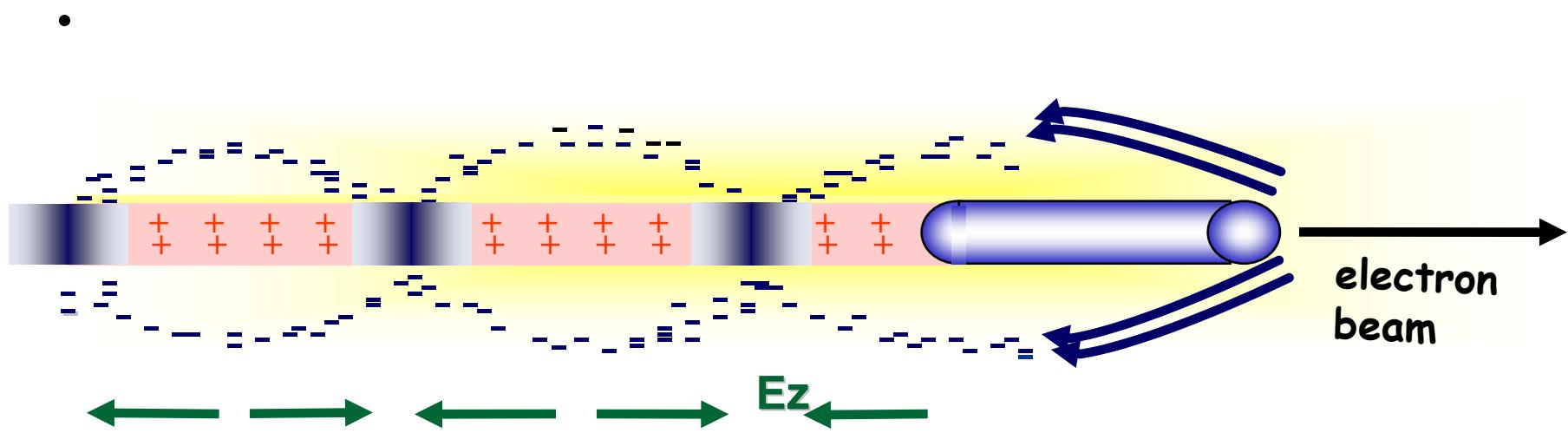
$$n_p < n_b / \gamma^2$$
 unfocused

$$n_p < n_b$$
 ion-focused

$$n_p > n_b \quad k_p \sigma_r \ll 1$$
 magnetically self-focused

$$n_p > n_b \quad k_p \sigma_r > 1$$
 current neutralization

HEDS WITH ULTRA-RELATIVISTIC BEAMS



- Space charge of **beam** displaces **plasma electrons**
- Plasma ions exert restoring force => **Space charge wake**

- Wake amplitude

$$\propto N_b / \sigma_z^2$$



What is the Ion focused Regime for U-REB?

For a bi-Gaussian beam:

$$n_{bo} = N / (2\pi)^{3/2} \sigma(r) \sigma(z)$$

$$n_{bo} > n_p$$

$$k_p \sigma_r < 1$$

$$k_p \sigma_z \sim 1$$

$$\omega_p / k_p = c$$

$$E_r = 9 \times 10^{-15} n_e (\text{cm}^{-3}) \sigma_r (\mu\text{m}) \text{ MV/m}$$

$$E_z = 240 \text{ MeV/m} (N / 4 \times 10^{10}) (0.6 / \sigma (\text{mm})^2)$$

$$\text{For } n_e = 5 \times 10^{17} \text{ cm}^{-3}$$

$$\sigma_r = 5 \mu\text{m}$$

$$\sigma_z = 30 \mu\text{m}$$

$$N = 2 \times 10^{10}$$

$$E_r \sim 22.5 \text{ GeV/m}, B_{\theta/r} = 405 \text{ MG/cm}$$

$$E_z \sim 48 \text{ GeV/m}$$

Compelling Question :

High Energy Density Science with Ultrarelativistic Electron Beams:

Can the ultra high electric fields in a beam-driven plasma wakefield be harnessed and sufficiently controlled to accelerate high-quality, high-energy beams in compact devices?

Can plasma lenses focus such beams to unprecedented beam energy densities where they can be collided with sufficient luminosity for particle physics?



Physical Effects of Plasma Fields on the U-REB

TRANSVERSE (E_r)

Deflection
Focusing/Defocusing
Periodic Oscillations
Emission of Betatron Radiation

APPLICATION

Beam Steering
Plasma Lenses
Plasma Wigglers
Positron Production

LONGITUDINAL (E_z)

Acceleration
Deceleration

High Gradient Accelerators
Beam Dumps

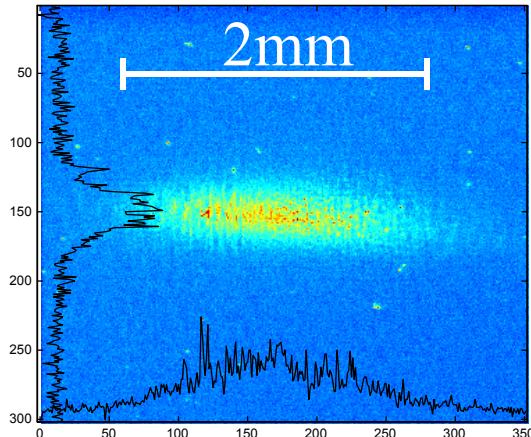
FOCUSING OF e^-/e^+



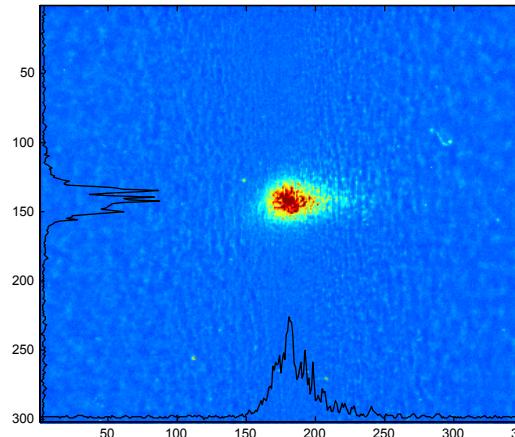
- OTR images $\approx 1\text{m}$ from plasma exit ($\varepsilon_x \neq \varepsilon_y$)

e^-

$$n_e = 0$$

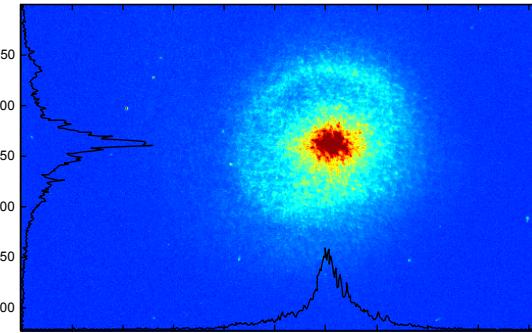
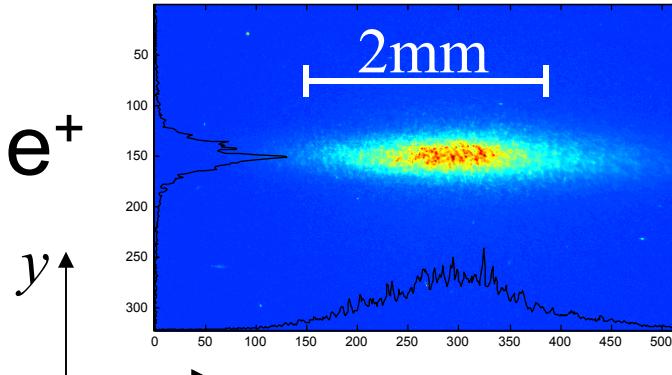


$$n_e \approx 10^{14} \text{ cm}^{-3}$$



- Ideal Plasma Lens in Blow-Out Regime

e^+



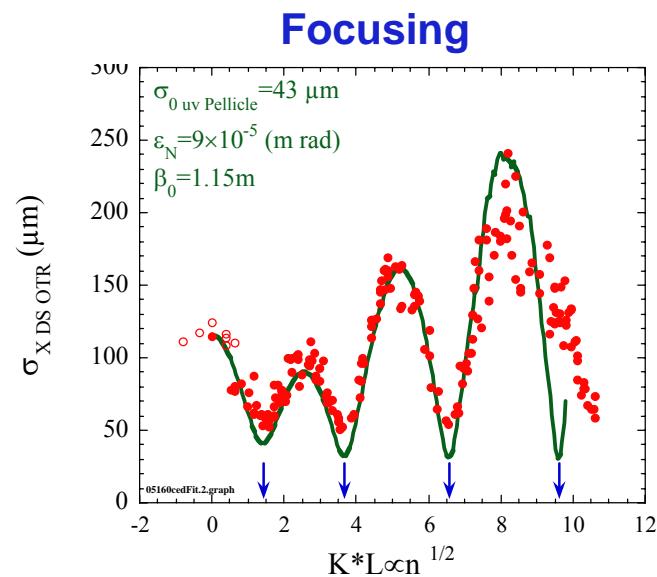
- Plasma Lens with Aberrations

- e^+ : halo formation from non uniform focusing (focusing aberrations)

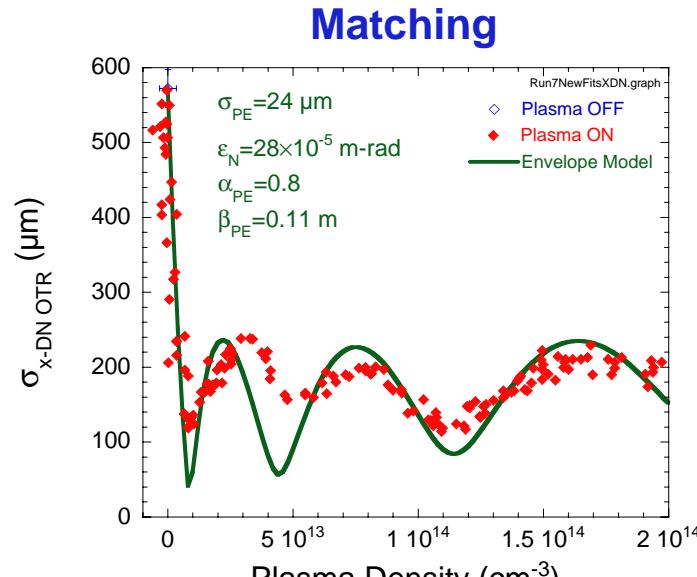


Previous Beam-Plasma Experimental Results (4 Highlights)

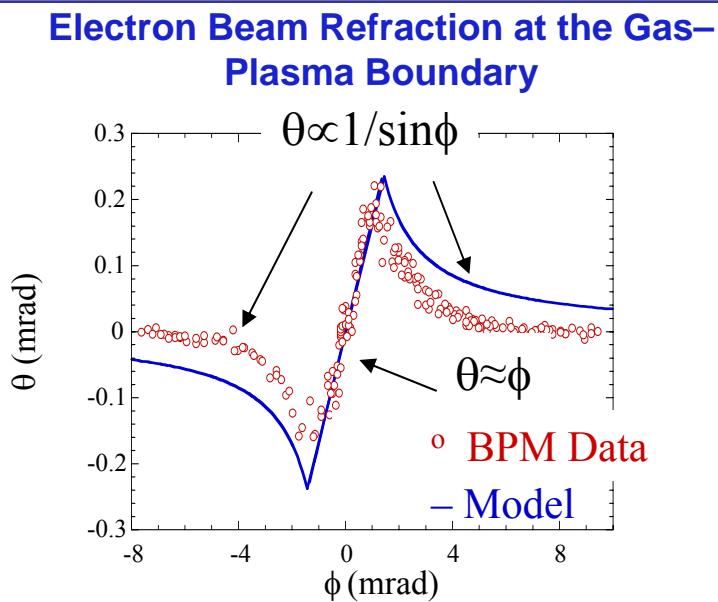
New Physics + Critical knowledge for Afterburner



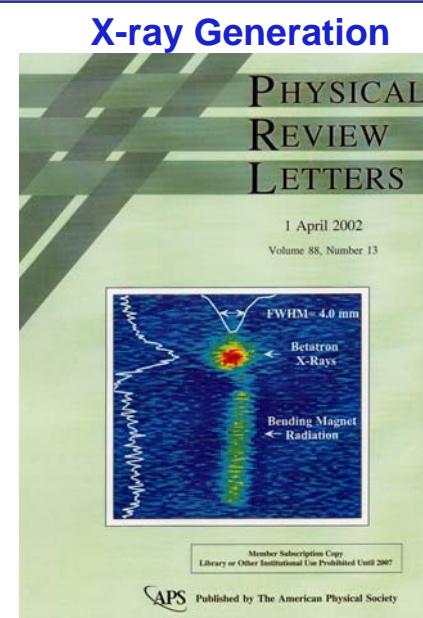
Physical Review Letters **88**, 154801 (2002)



Manuscript in Preparation

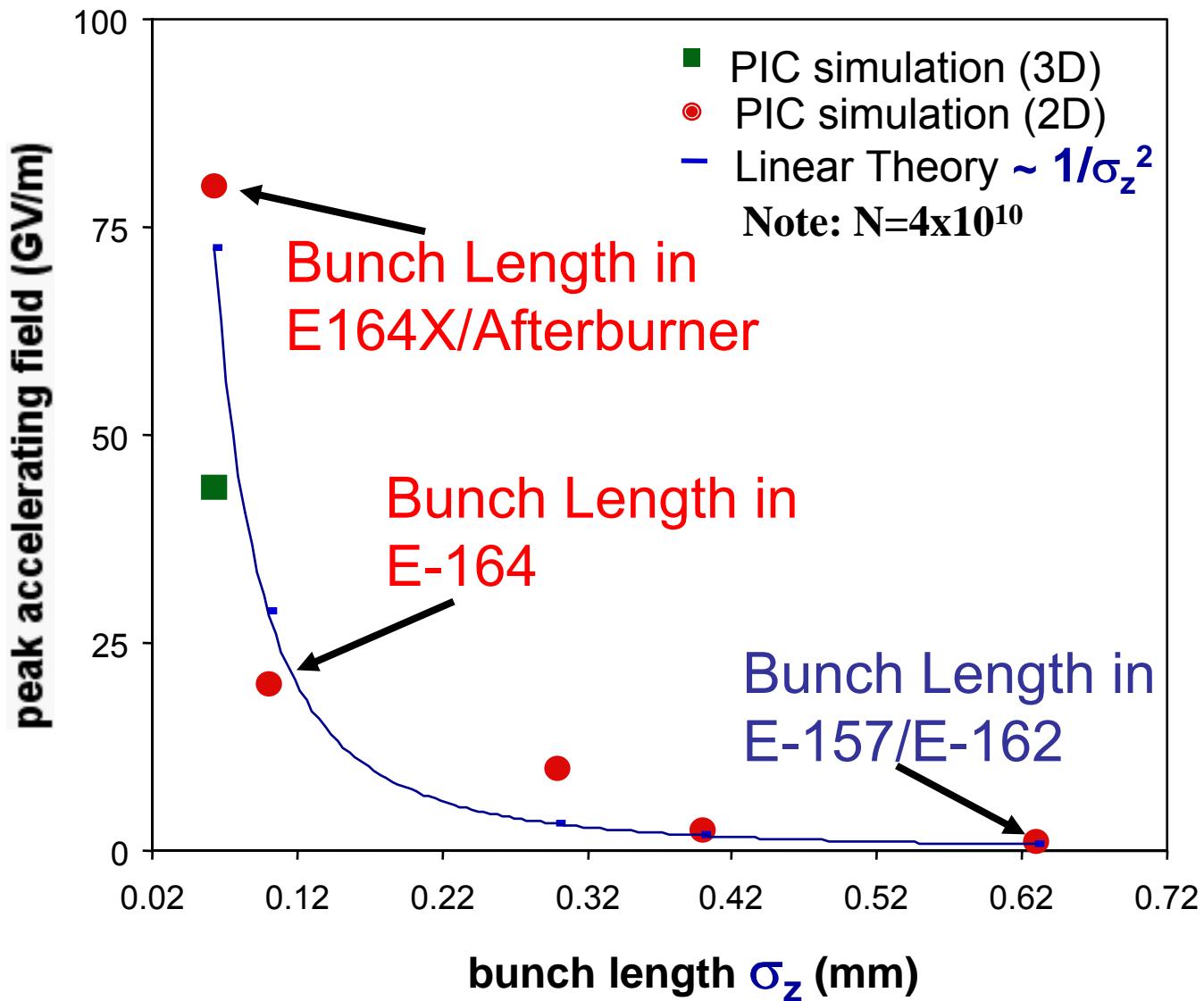


Nature **411**, 43 (3 May 2001)



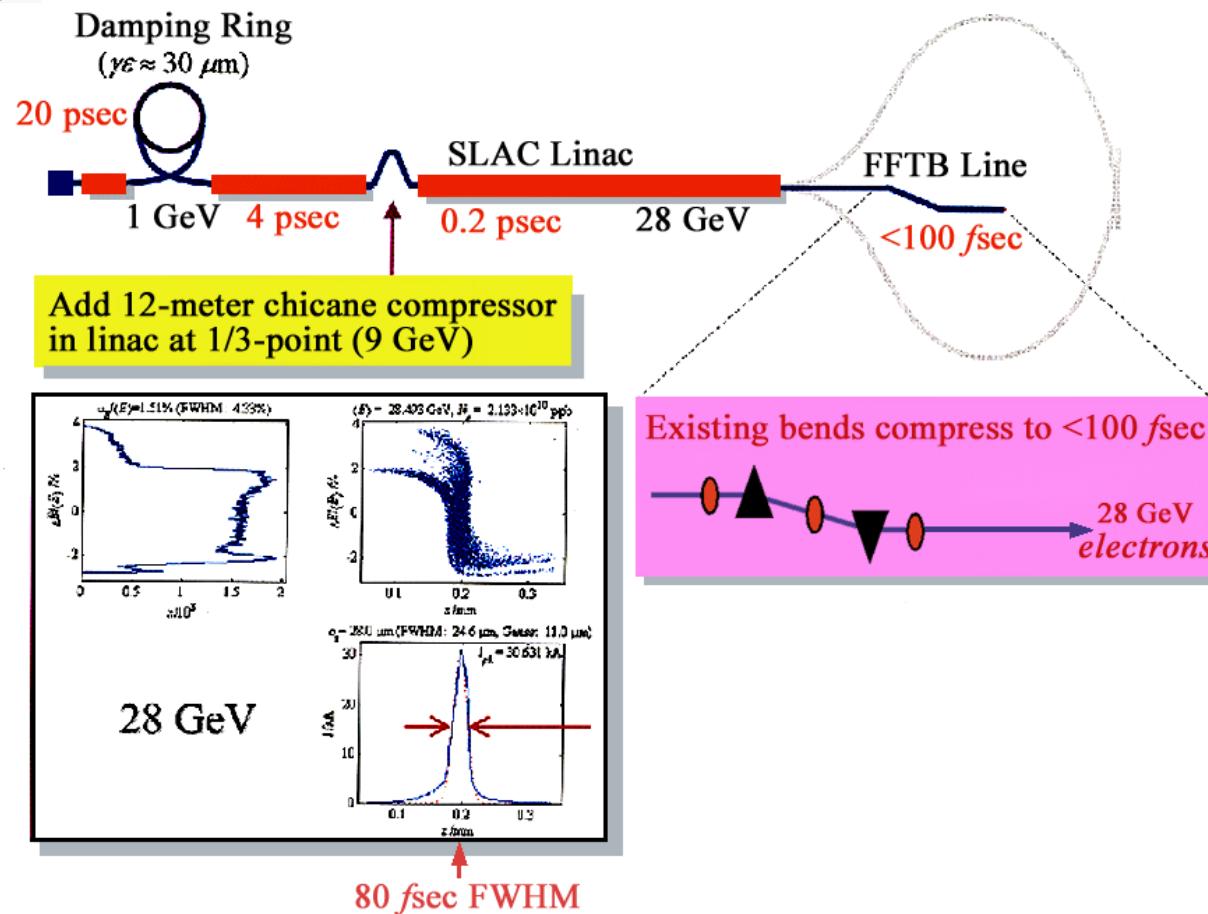
Physical Review Letters **88**, 135004 (2002))

PWA Experiments at SLAC





Sub-Picosecond Pulse Source



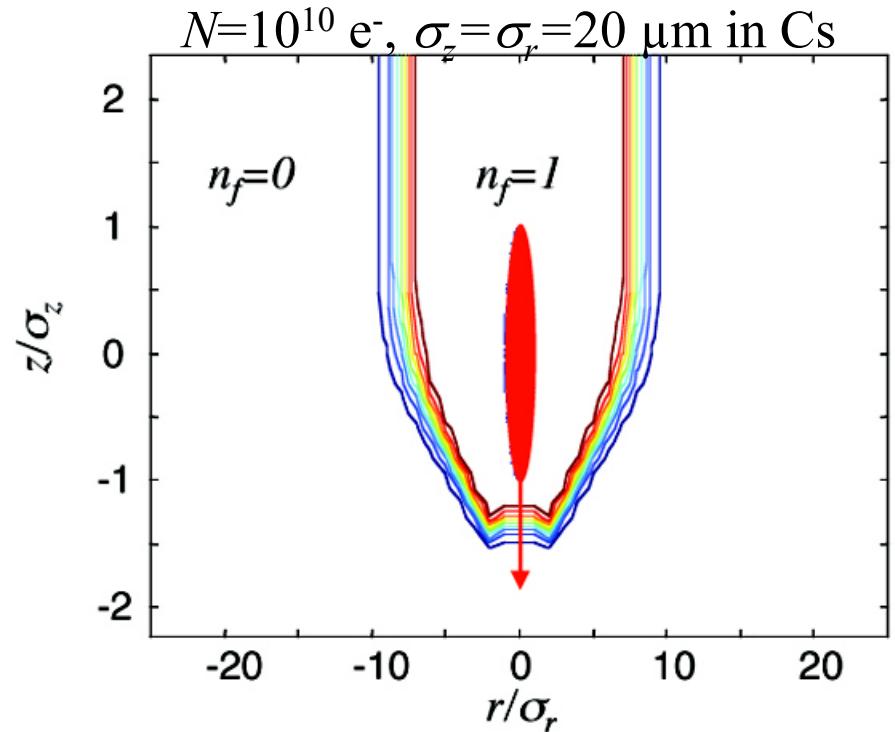
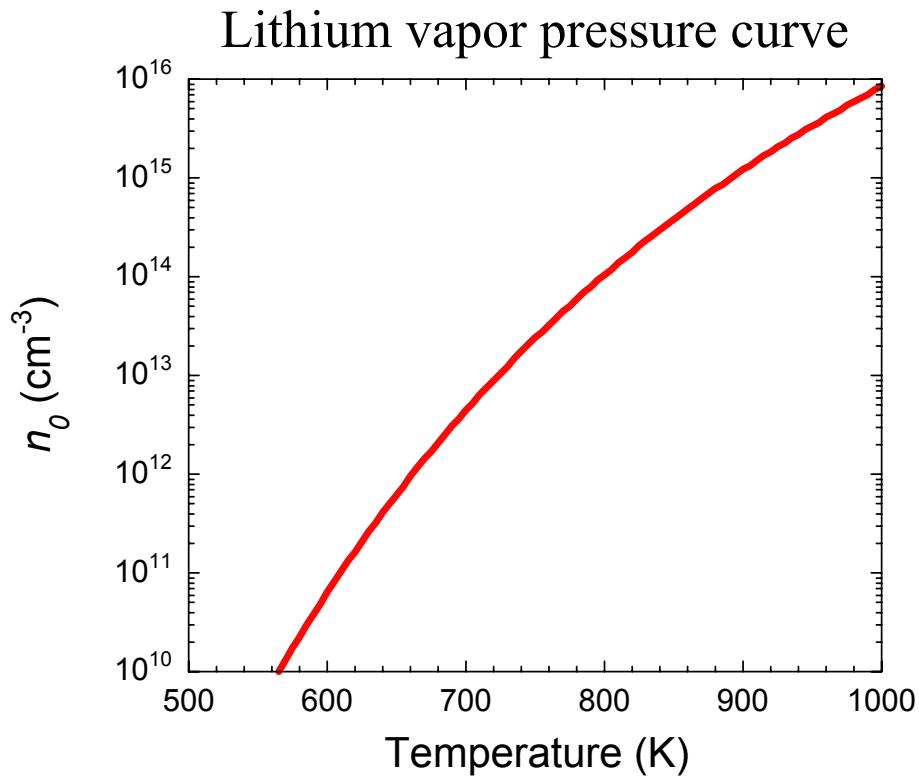
04/9-11/2003



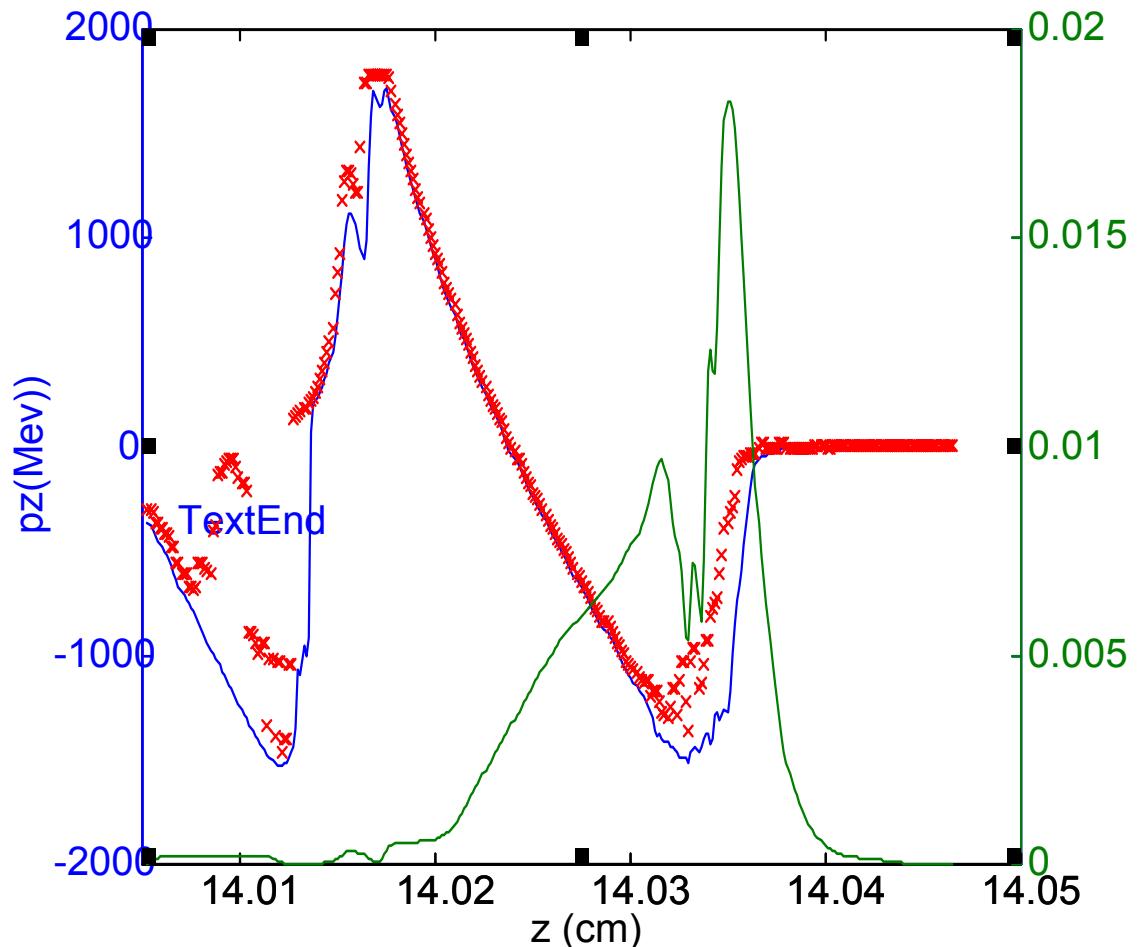
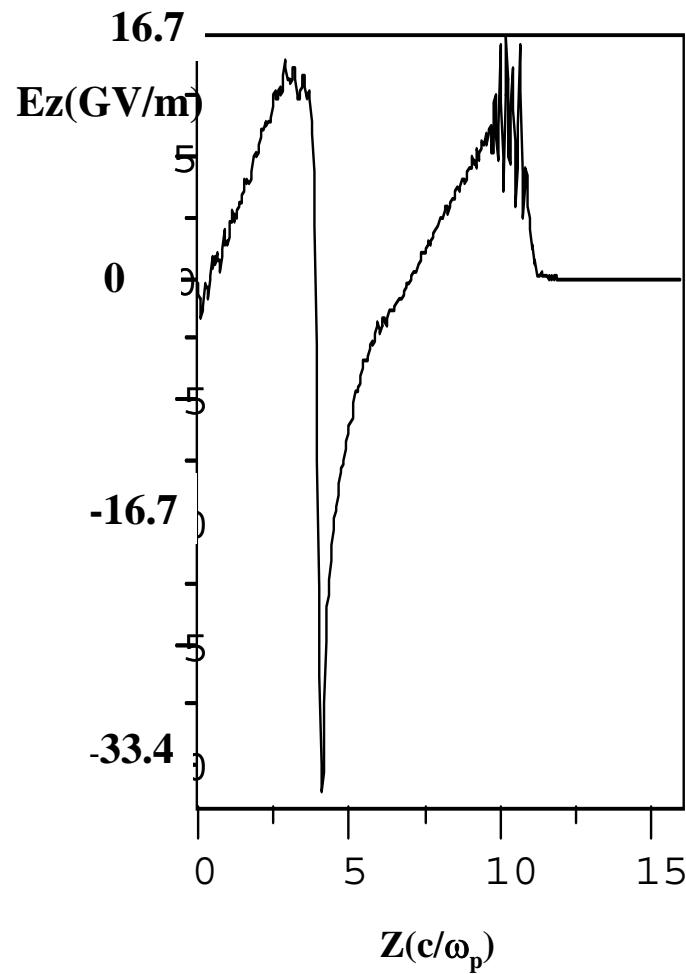
BEAM-IONIZED PLASMA



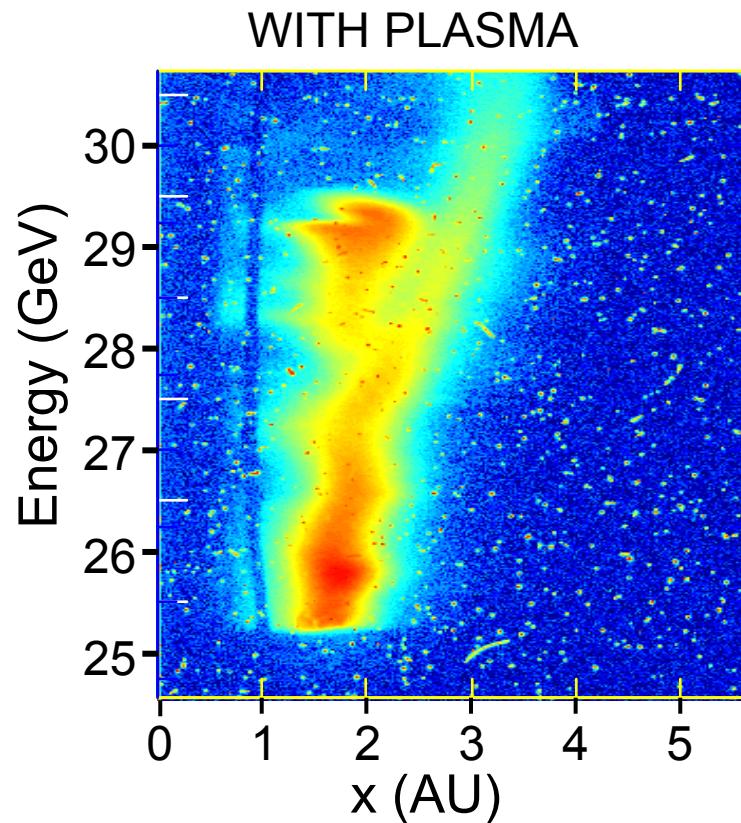
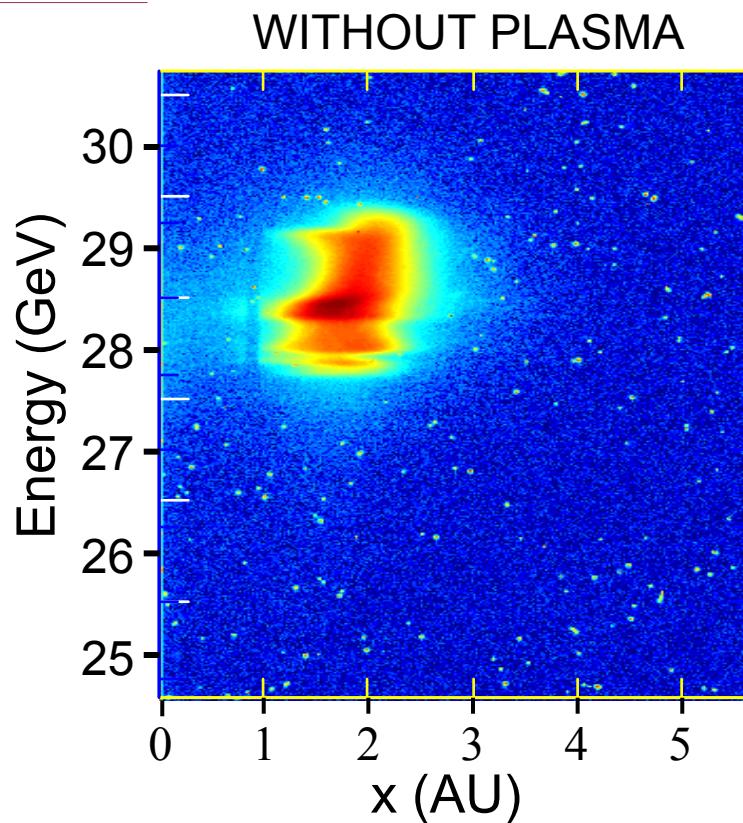
- Short bunch, $E_r \approx 5.2 \times 10^{-19} N/\sigma_z \sigma_r$ (GV/m) > tunneling field (Keldish, ADK)



E164X simulation results



Preliminary Results from E-164 (Run II)



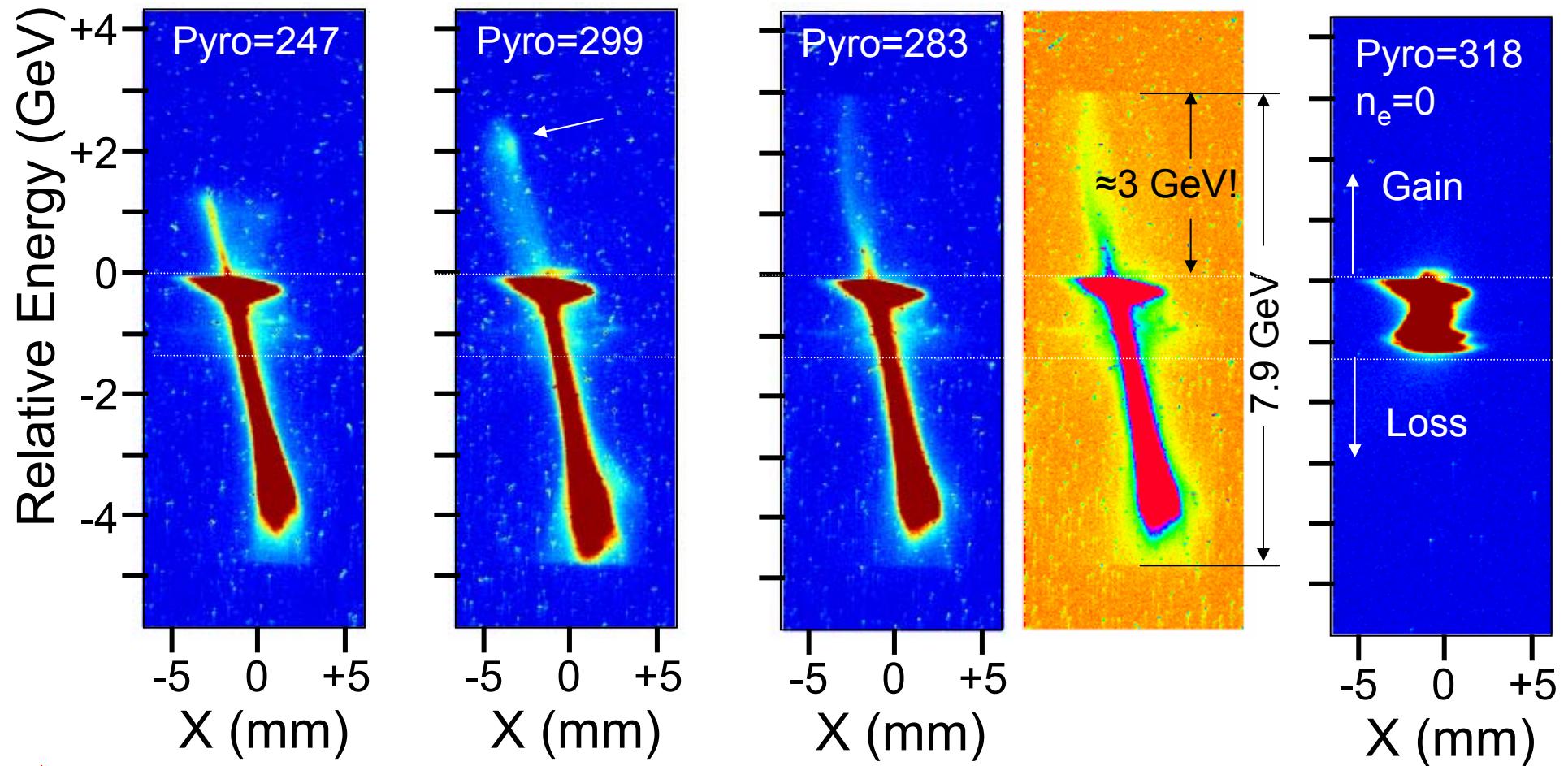
$$n_e = 3 \times 10^{16} \text{ cm}^{-3}, L = 15 \text{ cm}, N = 1.8 \times 10^{10}$$

- Energy loss of ~ 2.5 GeV
- Energy gain of > 2 GeV.



$n_e \approx 2.55 \times 10^{17} \text{ cm}^{-3}$ RESULTS

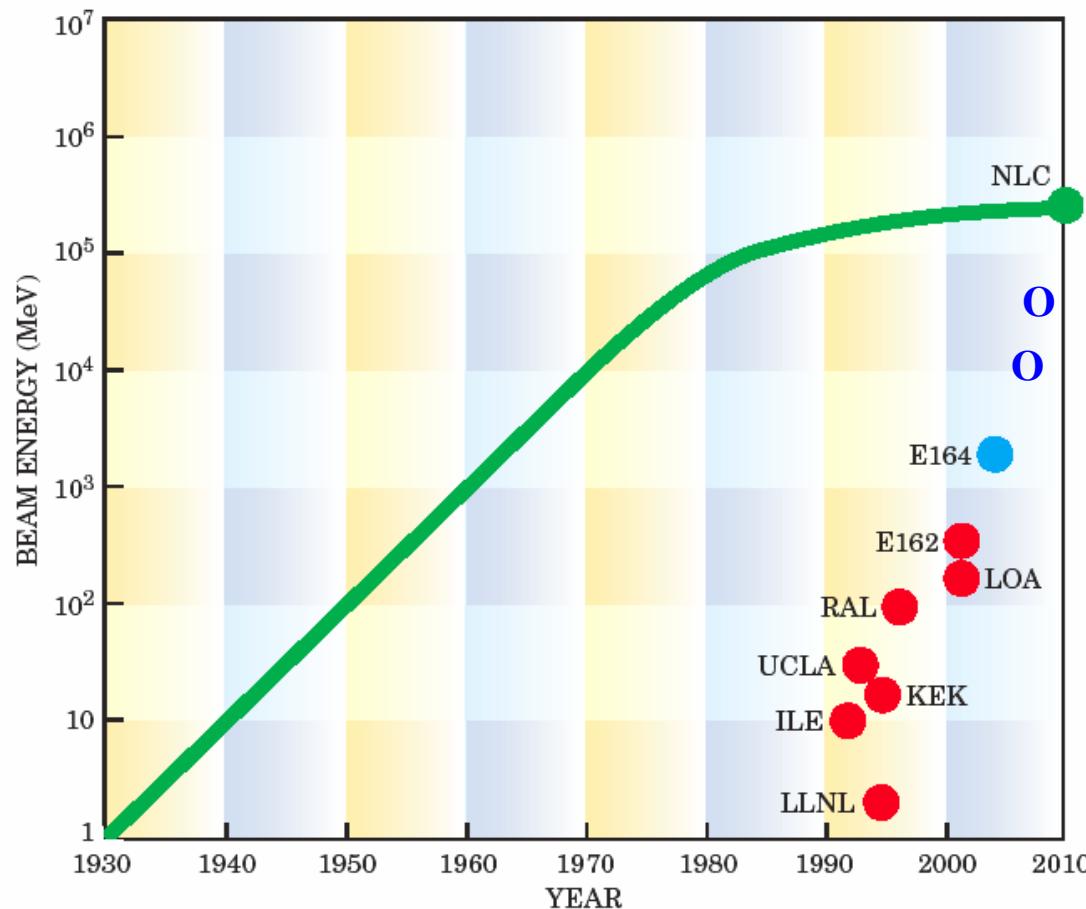
$L \approx 10 \text{ cm}, N \approx 1.8 \times 10^{10}$

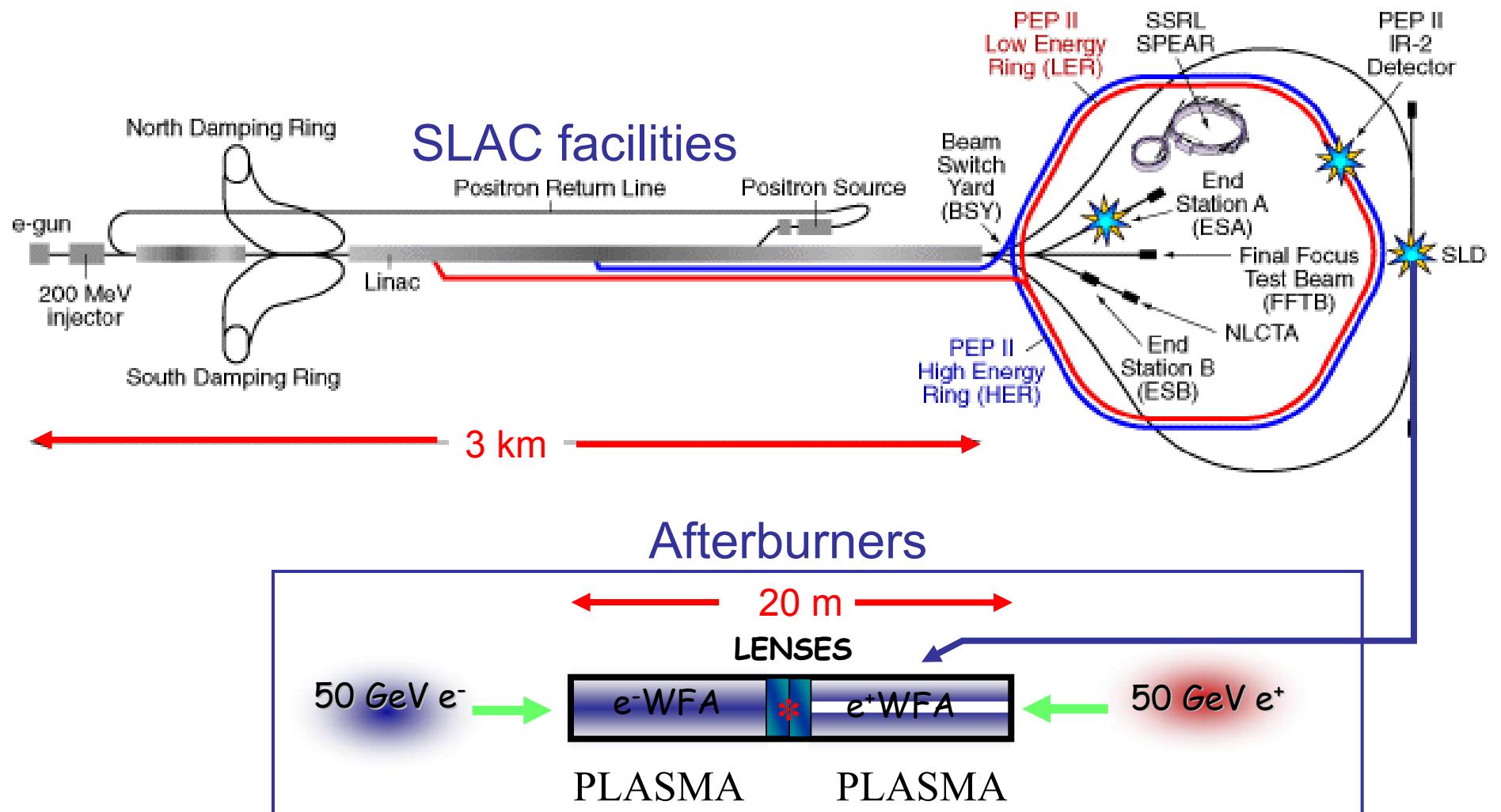


- Energy gain reaches $\approx 3+1$ GeV
- Energy gain depends on the details of the incoming beam (x,y,z)



Plasma Accelerators and the Livingston Curve







E-162/E-164/E-164X PWA Experiments

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